DEVELOPMENT OF DRILLING FLUID SYSTEM USING CARBOXYMETHYL CELLULOSE (CMC) FOR HIGH TEMPERATURE-HIGH PRESSURE (HTHP) APPLICATIONS

WINSON SIA SHEN LOONG

UNIVERSITY MALAYSIA PAHANG

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WINSON SIA SHEN LOONG

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Universiti Malaysia Pahang

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ABSTRACT

This dissertation deals with a means of reducing the effects of thermal degradation that commonly occurs in drilling fluids. The objective of this dissertation is to determine the viability of the interaction between carboxymethyl cellulose (CMC) with bentonite to increase the resistance of water based drilling to high temperature degradation which normally occurs at 121°C. Drilling fluids are used in drilling operations for many purposes such as removing drill cuttings and cooling the drill bit. These days, petroleum supply are running low causing drilling operations to move further offshore which requires drilling fluids that are able to withstand high temperatures up to 177°C as well as high pressures up to 15ksi. Therefore, there is a need to develop drilling fluids for high temperature and high pressure (HTHP) applications. The degradation of drilling fluids results in changes of the drilling fluid properties such as viscosity and fluid loss control. Drilling fluids of various CMC-bentonite ratio are prepared and properties such as viscosity, gel strength, density as well as pH of the samples are studied. High temperatures of 200°C are then applied to the samples for a duration of 16 hours and changes in the properties of the drilling fluids of various CMC-bentonite content are observed. Results show that CMC-Bentonite interaction is a possible solution to thermal degradation of drilling fluids at HTHP conditions at 10% weight composition of CMC. However, further study needs to be conducted at CMC compositions below 10% to further verify this finding.

Keywords: drilling fluid, carboxymethylcellulose (CMC), bentonite, thermal degradation, offshore-drilling, viscosity, gel-strength, density, pH

ABSTRAK

Tesis ini membentangkan penyelidikan untuk mengurangkan kesan-kesan degradasi suhu tinggi terhadap lumpur gerudi Objective tesis ini ialah mengkaji kemungkinan interaksi antara ‘carboxymethyl cellulose’ (CMC) dengan ‘bentonite’ untuk meningkatkan ketahanan lumpur gerudi terhadap degradasi suhu tinggi yang biasanya berlaku pada suhu 121^{o}C. Lumpur gerudi digunakan dalam penggerudian telaga untuk pelbagai fungsi seperti mengeluarkan bendalir telaga serta menyejukkan kepala gerudi. Kini, simpanan minyak semakin kurang menyebabkan operasi penggerudian bergerak ke kawasan laut dalam yang memerlukan lumpur gerudi yang boleh tahan suhu tinggi sehingga 177^{o}C serta tekanan setinggi 15ksi Oleh itu, terdapat keperluan untuk menghasilkan lumpur gerudi bagi kegunaan suhu serta tekanan tinggi. Degradasi suhu tinggi menyebabkan perubahan sifat-sifat lumpur seperti kelikatan dan sifat kehilangan turasan. Lumpur gerudi dengan pelbagai komposisi CMC-bentonite di sediakan dan sifat-sifat seperti kelikatan, kekuatan gel, ketumpatan serta pH dikaji. Lumpur gerudi kemudian di panaskan pada 200^{o}C selama 16 jam dan perubahan sifat-sifat ditentukan. Data menunjukkan kemungkinan interaksi CMC-Bentonite sebagai penyelesaian untuk mengurangkan kesan-kesan degradasi suhu tinggi pada komposisi berat 10% CMC. Namun, kajian lebih lanjut pada komposisi CMC di bawah 10% perlu dijalankan untuk meverifikasikan penemuan ini.

Kata kunci: lumpur gerudi, carboxymethylcellulose (CMC), bentonite, degradasi suhu tinggi, penggerudian laut dalam, kelikatan, kekuatan gel, ketumpatan, pH

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LIST OF SYMBOLS

^{o}C	Degrees Celsius
^{o}F	Degrees Fahrenheit
ρ	Density
P	Pressure
L	Depth of Well

LIST OF ABBREVIATIONS

API	American Petroleum Institute
CMC	Carboxymethylcellulose
cP	Centipoise
HTHP	High Temperature-High Pressure
ksi	kilopound per square inch
NAF	Non-aqueous Fluids
RPM	Revolutions per minute
WBF	Water Based Fluids

CHAPTER 1

INTRODUCTION

1.1 Introduction

Many of Earth's valuable resources such as oil and mineral water can be found deep beneath the surface. Drilling has always been used to acquire these resources from the crust of the Earth and this has lead to the existence of drilling fluids to facilitate the process.

The earliest form of drilling fluid was just water, which has the basic functions of softening rock and bringing the cuttings out of the well (Henry C. H. Darley, George Robert Gray ,1988). With the progress of technology, drilling fluids now are far more functional than their ancestors with the capability to remove drill cuttings from the well, cool as well as lubricate the drill bit, stabilize the borehole wall,lubricate the drill pipe, reduce fluid loss from to the formation and suspend cuttings (SIEP: Well Engineers Notek, Edition 4, May 2003). Various kind of drilling fluids have emerged over the years such as Water Based Fluid (WBF) and Non-Aqueous Fluids (NAF) (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

Water based fluids uses fresh water or salt water as a base fluid with various additives such as weighting agents, viscosifiers and fluid loss control additives to control the properties of the drilling fluid as required in field applications.

Carboxymethyl cellulose (CMC) has been used as a viscosifier and fluid loss reducer in water based fluids since 1947 which indicates its reliability in drilling mud (Young & Maas, 2001). Kirk-Othmer (2004) also claims that CMC is one of the most widely used cellulosic in the drilling sector. CMC is a water-soluble cellulose produced from the carboxymethylation of water-insoluble cellulose (Kirk-Othmer Encyclopedia of Chemical Technology,Vol. 9, 2004). Studies have shown that polymers and lignite additives have the ability to affect the rheological properties of clay dispersion when interacted with clay minerals. This has made carboxymethyl cellulose (CMC) a viable substance for maintaining flow properties of drilling fluid at high temperature and pressure (Menezes, Marques, Campos, Ferreira, Santana, & Neves, 2010; Kelessidis, 2007).

Offshore drilling in the oil and gas industry usually deals with harsh environments where temperatures can go above 177^{o}C (350^{o}F) and pressures exceeding 15 ksi. Therefore there is a need for high temperature-high pressure (HTHP) drilling fluids capable of operating under such conditions (Baker Hughes Incorporated, 2009). Therefore, research are continuously needed in order to meet the demands of the industry for a dependable drilling fluid from a rheological aspect as well as environmental effect in order to maintain a safe and profitable well.

1.2 Problem Statement

Drilling fluids plays a significant role in the drilling sector to produce a safe, productive and cost effective well. As oil supply is decreasing**,** most oil and gas drilling operations are moving into deeper waters where high temperature and high pressure conditions become a challenge for drilling fluids. This has called for more studies into high temperature-high pressure (HTHP) application drilling fluids which are capable of operating effectively in such harsh conditions.

The thermal stability of drilling fluids become a concern under HTHP conditions as thermal degradation of the fluids can occur. Thermal degradation of drilling fluids can affect the properties of the fluid such as viscosity and suspension characteristics causing the fluid to be harder to predict thus becoming less effective or redundant.

Failure of drilling fluids to meet required specifications properly during drilling operations could result in devastating effects especially in HTHP conditions. Therefore, it is essential to prevent thermal degradation of drilling fluids in order to reduce the risk of unexpected and unwanted incidents.

Non-Aqueous fluids such as synthetic and oil based fluids are considered to be superior to their water based counterparts from various performance aspect especially in HTHP conditions. The reliability of these fluids is a major factor that these type of drilling fluids are preferred over aqueous fluids especially in deep sea environments. However, these fluids bring about a bigger environmental impact thus requiring proper treatment and disposal which incurs higher cost.

Water Based Fluids consist largely of fresh or salt water and typically start to degrade at temperatures of 121^oC (250^oF) which brings about a slight performance issue especially in HTHP applications. Thermal degradation issues have deterred the use of these fluids in HTHP environments except when environmental issues become a concern as water based fluids have lesser environmental impact. On the positive side, water based fluids have an edge from a cost aspect. Water based drilling fluids have a lower cost as it consist largely of water which is readily available. Besides that ,water based fluids can be more easily disposed without much treatment resulting in financial savings.

Water based fluids have advantages from environmental and cost aspects despite being prone to thermal degradation. As there are environments which non-aqueous fluids cannot be implemented, there is a dire need for water based fluids capable of withstanding HTHP environments without compromising reliability. Therefore, there is a need for further study into water based fluids for HTHP applications.

1.3 Objectives of Research

The objective of this research is to study the viability of CMC-bentonite interaction in water-based drilling fluid to reduce the effects of thermal degradation in HTHP conditions.

1.4 Scope of Study

In order to achieve the objective of this study, there are a few scopes that need to be addressed :

i. To produce drilling fluids with varying weight composition of CMC and bentonite (e.g 100% Bentonite, 90% Bentonite-10% CMC, 80% Bentonite-20% CMC)

ii. To measure the viscosity, gel strength, density and pH of drilling fluid before and after exposure to heat 200^{o}C.

iii. To determine composition of CMC and bentonite which has least changes in properties after exposure to heat.

1.5 Rationale and Significance

1.5.1 HTHP Condition

Drilling operations are now heading into deeper seas as easy-to-reach oil wells are beginning to deplete. Deep sea wells pose quite a challenge due to high temperature and high pressure conditions which can cause thermal degradation of drilling fluids. This indicates the need for drilling fluids capable of withstanding high temperature and high pressure conditions. This is further supported by the statement of Jim Friedheim, Director of Corporate Fluids Research and Development of M-I SWACO**,** that it is essential to develop drilling fluids to accommodate the need of deeper waters where the environment is demanding (Cox, 2010).

In addition to that , as the depth of drilling increases so does the challenges that come with drilling as the environment becomes more hostile. Mr Dave Beardmore , a drilling fluids specialist of ConocoPhillips concur that sustaining mud properties at high temperature high pressure conditions is a obstacle that needs to be conquered. This further supports a need to research drilling fluids for HTHP conditions (Cox, 2010).

1.5.2 Cost

In any business or operation, profit is a major goal or objective that needs to be achieved. Cost reduction is an essential part of generating more profit. Drilling fluids tend to make up 5%-10% of total well cost which indicates that a reduction in drilling fluid cost can significantly affect the total cost of drilling operations (Allan McCourt & Robert Copeland, 2007).

The use of water based fluids can significantly reduce cost as water based fluids are more cost effective than non aqueous fluids. This is firstly due to the components within the fluids which largely consist of water making it much cheaper than non-aqueous fluids. Therefore, production cost is an important aspect the study is inclined towards the production of water based fluids (Neff, 2005).

Furthermore, due to the toxicity of non aqueous drilling fluids, cuttings that contain high amounts of drilling fluids have to be disposed upland which incurs cost. Water based fluids on the other hand, the cuttings can be discharged into the sea which reduces processing cost. Therefore, aqueous drilling fluids have the potential to significantly reduce overall cost of drilling operations (Menezes, Marques, Campos, Ferreira, Santana, & Neves, 2010).

1.5.3 Environmental Issues

Various acts and regulations are imposed on companies when it comes to the disposal of drilling fluids into the environment. Components in drilling fluids are considered a threat to the environment when it exceeds the permissible limit and it becomes the responsibility of companies to dispose of drill cuttings and drilling fluids responsibly. Taking cost and environmental factors into account, water based fluids is considered to be the best solution but thermal degradation of the fluid remains an issue. These further emphasizes the need for a water based fluid that can cope with the various challenges of HTHP conditions (Kelessidis, 2007).

1.5.4 CMC

Carboxymethyl cellulose (CMC) has been used in drilling fluids for more than half a century which is prove of its reliability in drilling fluids as a viscosifier and fluid loss controller (Young & Maas, 2001). Therefore by working with a readily available substance, time and cost can be reduced as there is no need to research a new material. In addition to that, previous study indicates that CMC has the ability to maintain flow properties under high temperature and high pressure conditions in the presence of bentonite clay as a result of interaction between the two subtances (Menezes, Marques, Campos, Ferreira, Santana, & Neves, 2010).

CHAPTER 2

REVIEW OF RELATED LITERATURE

2.1 Drilling Fluids

Drilling fluids are substances that aid in the creation of boreholes. It is a major part of drilling operations as it creates an optimum condition for drilling to be carried out effectively and efficiently as well as increases productivity of the well (Darley & Gray, 1988)**.** Drilling fluids are used for various drilling applications whereby the most challenging is offshore drilling at high temperature and high pressure conditions. Drilling fluids are also referred to as drilling mud and can be divided into two types which are aqueous drilling fluids as well non-aqueous drilling fluids. The fluids serves a few primary function which are (WDC Exploration & Wells) :

i. Removes cutting from borehole and cleans the drill bit

    As drilling is done , cuttings which are the drilled material build up within the hole. Therefore it is essential for the cuttings to be removed for drilling to proceed smoothly. Drilling fluids achieve this goal by bringing the drilled material to the surface by the use of velocity or viscosity. The removal of cuttings also cleans the drill bit to avoid re-cut of cuttings.

ii. Cool and lubricates the drill bit

    Heat is generated by the friction between drill bits and the cuttings. The drilling fluids which are circulated in the well serve to transfer the heat from the drill bit back up to the surface thus cooling the drill bits. In addition to that, the presence of the fluid reduces the friction between the blades and the cuttings.

iii. Lubricates the drill pipe

Friction can occur between the drill pipe and the formation as well as the cuttings. The presence of the drilling fluid serves as a barrier which reduces this friction and thus prolongs the life of the pipe.

iv. Controls fluid loss

Fluids in the borehole have a tendency to move into the formation which could result in a loss of drilling fluids. Therefore it is necessary for a barrier known as a filter cake to prevent the fluid loss. This can be achieved through the deposition of clay particles on the borehole wall. A successful reduction in fluid loss can reduce well development time.

v. Stabilise the borehole

Boreholes can collapse if formation pressure gets too high. Therefore it is necessary to overcome this pressure with the use of drilling fluids' weight in order to maintain the structure of the borehole. In addition to that, drilling fluids also form an impermeable barrier to prevent the formation from swelling and close in on the drill pipes.

vi. Suspend cuttings

Fluid velocity is essential in carrying cuttings out of the hole. However the drilling fluid also needs to be able to hold the cuttings in suspension when the pump stops and the fluid losses its velocity. This avoids cuttings from settling back into the bottom of the borehole.

2.2 Development of Drilling Fluids

The earliest form of drilling fluids used were water which is still used in drilling fluids till this very day. In the past, drilling fluids serve a simpler purpose which was just to remove cuttings and soften the rocks. The idea about the circulation of fluid only came up around the year 1844 where it was proposed that cuttings can be removed by water.

In 1887, hole stabilization came into existence when the suggestion of using water with a plastic material to support the wall of the holes and increase stability of the hole. Later on in the 1890s, mud and clay became a common substance for hole stabilization. Even back in those days, the demand for a reliable hole stabiliser was high.

Mud density was later seen as a means of pressure control within boreholes. Density supports the filter cake which prevents penetration of fluids into the formation thus controlling pressure within the borehole. Various additives such as cement, galena and iron oxide were tested as weighting agents. In 1922, barite was used to make heavy mud and is used till this very day. (Darley & Gray, 1988)

All this progress throughout the years revolutionised the mud industry and has been continuously developing ever since. This is an indication of the path of the industry and constant development required to face the challenges that comes with drilling. Drilling fluids now have various roles which makes them important in sustaining a safe and effective drilling operation.

2.3 Types of Drilling Fluids

Drilling fluids can be divided into various types according to their base fluids which are water based, oil based or synthetic based.

2.3.1 Water Based Drilling Fluids

Water based fluids are drilling fluids which uses fresh water or salt water as its base material. The fluid also consist of various water soluble additives with different functions to improve properties of the fluid to meet the requirements of the borehole. These additives include viscosifiers, weighting agents and fluid loss controllers.

Water based drilling fluids have been proven to be more cost effective option both in initial cost as well as drill cutting disposal cost. In addition to that, water based drilling fluids have been proven to be more environmental friendly than other drilling fluids as the base material itself is merely water which pose no threat to the environment (Neff, 2005)**.**

However, a down point would be that water based fluids are prone to thermal degradation at temperatures above 121^{o}C (250^{o}F). Thermal degradation affects the properties of the fluids which makes it less reliable in high temperature-high pressure (HTHP) (Baker Hughes Incorporated, 2009). Water based fluids usually consist of water, barite, clay/polymer and other necessary additives.

2.3.2 Oil Based Drilling Fluids

Oil based drilling fluids are non-aqueous fluids which as the name suggest use hydrocarbons as its base fluid instead of water. Due to this, oil based drilling fluids have better lubricating properties as well as better temperature tolerance which makes such fluids preferable for high temperature high pressure conditions.

However, the implementation of strict environmental regulations have prevented the disposal of cuttings with oil based fluids offshore which has somewhat limit the use of oil based drilling fluids in certain environments. This environmental factor also increases the cost of the operation as drill cuttings need to be properly processed and disposed.

The initial cost of oil based drilling fluids are also very costly as hydrocarbon prices are on the rise. The cost of the fluids are so high that industries consider reprocessing the fluids to reduce total cost (Neff, 2005). The fluids normally consist of oil, barite, brine ,emulsifiers, gellants and other additives (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

2.3.3 Synthetic Based Drilling Fluids

Synthetic based drilling uses synthetic substances such as synthetic hydrocarbons, ether, ester, acetal or a combination as a base fluid. Synthetic based fluids were developed to have the reliability of oil based drilling fluids and yet be more environmental friendly than conventional oil based drilling fluids.

Base fluids are specially produced to meet the requirement of the well which makes it more costly than both oil and water based fluids. As a result of the high cost, synthetic based fluids are usually reused rather than disposed into the environment.

Cuttings are allowed to be discharged if chemical on cuttings do not exceed environmental limits imposed on the drilling location. The limits are commonly 6.9% for internal olefins and 9.4% for esters (Neff, 2005). Compositions of synthetic drilling fluids are similar to that of oil based fluids but the oil is replaced by synthetic chemicals (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

2.4 Water Based Fluid Ingredients

The ingredients within drilling fluids can be divided into various functional groups such as weighting agents, viscosifiers, pH-control additives and fluid loss control additives.

2.4.1 Weighting Agents

Weighting agents are used to increase the density of the drilling fluids. The density prevents wall cave-ins by balancing the formation pressure. This in turn also prevents blowouts from occurring. Barite, hematite, ilmenite and calcite are examples of weighting agents.

Barite is one of the most commonly used weighting agents in offshore drilling. Barite has the ability to increase density of water by more than two times the density of water. Barites used for offshore drilling fluids should have a purity of 92% and a density of more than 4.2g/cm^3 (Neff, 2005).

2.4.2 Viscosifiers

Viscosifiers are essential in sustaining gel strength which serves to suspend as well as carry drill cuttings to the surface. Slurries with viscosifiers tend to liquefy when rotation is present and prevents cuttings and barite from settling when drilling is stopped. This is an essential in maintaining an effective drilling operation.

Bentonite clay as well as natural polymers such as cellulose and starch are examples of viscosifiers. Polymers are beginning to replace bentonite clay in soft formations as they maintain viscosity better while not damaging the soft formation. However, use of natural polymers such as CMC are often limited to lower temperature applications as they become prone to thermal degradation and affect their ability as a viscosifier (Neff, 2005).

2.4.3 Fluid Loss Control Additives

Additives in this category serve to reduce loss of fluid from the hole into the formation by forming filter cakes on the walls of the hole. The filter cake serves as a boundary that prevents movement of fluids into the wall formation therefore maintaining the fluid within the borehole. The prevention of fluid loss also prevents build up of fluids in the wall which can lead to swelling that can cause walls to close in on drill pipes . Both bentonite clay and CMC in the presence of sodium are examples of fluid loss controllers (International Petroleum Industry Environmental Conservation Association (IPIECA) ; International Association of Oil & Gas Producers (OGP), 2009).

It is essential to prevent fluid losses to the formation so fluid loss can lead to an in increase well development time. The presence of a filter cake also strengthens the structure of the hole creating a safer drilling operation (WDC Exploration & Wells).